P2944 / TPF

UNIVERSITY OF PENNSYLVANIA
PRELIMINARY TECHNOLOGY DISCLOSURE FORM
PLEASE SEE REVERSE SIDE FOR INSTRUCTIONS

Date Submitted __07/25/02___________

1. **Disclosure Title.** _____**Trabecular Bone Thickness Measurement at Limited Reso;ution Regimes by Fuzzy Distance Transform**___________

2. **Relation to Previous Disclosure:** Yes _X__ No ____ If Yes, file number and title: __N-2493_&_O-2705______________________

3. **Possible Obligations to Others:**
   Funding:
   NIH/Government__NIH_ Grant #:___R21 47112 and RO1 41443__________ Corporate or Other ______ Sponsor Name ______________________

   Related Agreements:
   _X_ Sponsored Research Agreements ___ Material Transfer Agreements
   ___ Collaborative Agreements ___ Inter-Institutional Agreements

   Other Parties (Include name/phone #, organization) ______________________

   Materials:
   Did you use any material obtained from another party in developing this technology? Yes ____ No __X__ Source ______________________

4. **Critical Dates:**

	Circle One:	Date:	Describe:
-- Disclosure or presentation to others?	No (circled) Yes	________	Who/Affiliation? ______________________
-- Submitted as an abstract or manuscript?	No Yes (circled)	________	Expected Publication? _________Published 2002___________
-- Submitted in grant application or report?	No Yes (circled)	________	Expected Funding? ______________________
-- Published in any form - including internet?	No Yes (circled)	________	Where Published? _____SPIE MI-02, ISMRM-02, CVIU-revised_______ Feb, 2002 → meeting

Please include a copy of any such abstracts, manuscripts or grants with your Form.

5. **Commercialization:**

What products, processes or services would result from your technology?______________EVS Corporation, ENVISIA______________
Do you know of (please provide names and contact information if possible):
Colleagues working in complementary areas? ______________________
Companies that might be interested in licensing your technology? ______________________

6. **Contributors:** I/We hereby submit this in accordance with University policies:

Signature(s)	Name (print)	Citizenship	School & Dept (or Institution if not Penn)	Phone #	Email
[signature] [Primary Contact]	Punam K Saha	Indian	School of Medicine, Radiology	662-6780	saha@mipg.upenn.edu
[signature]	Felix W. Werhli	Swiss	School of Medicine, Radiology	662-7951	wehrli@oasis.rad...

7. **Description of Technology: (VERY IMPORTANT) CTT cannot assess the protectability, technical merit and commercial potential of your disclosure without this information. Attched.**

Please provide in hard copy and on electronic disk (IBM), if possible.
1) Grant applications and manuscripts describing the technology (as above).
2) Curriculum vitae (CV) of inventor(s).
3) Related publications and patents by you and others working in this field.
4) A concise description of the technology (2-5 pages), including the following:
   a) Brief Summary
   b) Stage of Development (Are there any problems with your present technology? Is there a need for additional funding, time, etc.?)
   c) Applications/Commercial use of the technology/Products or services envisioned
   d) Closest known similar technology or competing products
   e) Differences and advantages over other technology or products.

EXHIBIT
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University of Pennsylvania
Preliminary Technology Disclosure Form: Instructions

This Preliminary Technology Disclosure Form is an abbreviated form for use by University faculty, staff and students when they wish to report the creation of intellectual property. It is designed to provide the staff of the Center for Technology Transfer ("CTT") with enough preliminary information to open a file and initiate the case review process.

Upon receipt of this Form, your Disclosure will be officially docketed and assigned to a Director in the CTT with the most relevant scientific and commercial background.

The requested information is as follows:

1. **Disclosure Title.** The title should be general and not disclose key aspects of the technology.

2. **Relation to Previous Disclosure.** Any related technology(s) previously disclosed to the CTT should be listed.

3. **Possible Obligations to Others.** If this technology is/was funded by a government, foundation or corporate source, please provide all grant numbers and list any additional obligations to other parties.

4. **Critical Dates.** Provide key dates in the disclosure of the technology including all past and future dates of presentations or publications.

5. **Commercialization.** Please provide your ideas on the most likely commercial path for your technology.

6. **Contributors.** All persons contributing to this technology should sign and be identified in this section.

7. **Description of Technology.** On a separate page(s), please provide a summary of the technology. Please be sure to address all the items listed and provide both hard copy and disk, if possible. Emphasize the commercial utility, applications, differences and advantages of your technology.

Attachments. An extended description of the technology and its background is often helpful, including grant applications, abstracts, manuscripts, photos, illustrations, and the like. A bibliography, reprints, and pre-prints of related technologies by your laboratory and/or others also helps the review.

If assembly of all the requested materials will significantly delay submission of this Preliminary Technology Disclosure Form, submit it now, and gather the additional materials for later submission.

This completed Preliminary Technology Disclosure Form and supporting materials should be HAND DELIVERED to the Center for Technology Transfer, 3700 Market Street, Suite 300, in a sealed envelope marked "CONFIDENTIAL."

If you have any questions, please feel free to call the Director of Intellectual Property, at 215-573-4508.

CENTER FOR TECHNOLOGY TRANSFER
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For CTT use only:
Docket No.: P2944
Date Received:
Received by:
Docketing Date:
Docketed by:
Assigned to: TPS

AUG - 7 2002

A Brief Description of the Technology

(1) **Any grant applications or manuscripts describing the technology:**
 (4) P. K. Saha, B. R. Gomberg, and F. W. Wehrli, "A novel theory and algorithm of fuzzy distance transform and its applications", in *Proceedings of SPIE: Medical Imaging*, San Diego, CA, **4684**, 134–145, 2002. → June or July, 2002
 (5) P. K. Saha, F. W. Wehrli, B. R. Gomberg, and M. Takahashi "Trabecular bone thickness from *in vivo* MRI using fuzzy distance transform", in *Proceedings of International Society for Magnetic Resonance in Medicine*, pp. 146, Honolulu, HI, 2002.
 (6) P. K. Saha, F. W. Wehrli, and B. R. Gomberg, "Fuzzy distance transform — theory, algorithms, and applications" *Computer Vision and Image Understanding*, accepted under revision.

(2) **Current curriculum vitae (CV) of inventors:** Attached on separate sheets.

(3) **Closest related publications by you or others, or other prior art:**
 (4) Rutvitz, D., "Data structures for operations on digital images," in *Pictorial Pattern Recognition*, pp. 105-133, 1968.
 (5) G. Levi, U. Montanari, "A gray-weighted skeleton," *Information and Control*, **17**, pp. 62-91, 1970.

(4) **A concise description of the technology:**

The thickness of trabecular bone is an important architectural determinant of bone strength [1]. Corticosteroid exposure, for example, is well known to cause trabecular thinning [2]. Conversely, treatment with anabolic agents, such as parathyroid hormone, causes trabecular thickening. Recent advances in micro-MRI now allow visualization of trabecular networks *in vivo.* However, accurate measurement of trabecular thickness poses significant hurdles since *in vivo* resolution is usually not sufficient to fully resolve the structures of interest.

Distance transform (DT) provides depth information at any point inside a structure. The method described in this invention is based on sampling DT values along the medial axis thus yielding a regional thickness measure. However, whereas DT has previously been applied to binary images (see [3, 4] for early intensity based DT) such representations fail to handle object material heterogeneity and partial volume effects. Partial volume blurring is particularly severe at *in vivo* resolution of MRI and CT images of trabecular bones since the voxel size is typically comparable to or larger than trabecular thickness. It is well known that under these conditions the images cannot be binarized and the DT of hard objects fails (see, for example, Wehrli FW, Hwang SN, Song HK, Gomberg BR 2000 Visualization and analysis of trabecular bone architecture in the limited spatial resolution regime of in vivo Micro-MRI. In: Majumdar S, Bay BK (eds.) Noninvasive assessment of trabecular bone architecture and the competence of bone. Kluwer, Big Sur, California, pp 153-164). The present invention overcomes the limitations intrinsic to binary distance transforms with a method capable of generating distance transforms of fuzzy objects referred to as *fuzzy distance transform* (FDT). The method can be understood by considering the paths between two points in a fuzzy object. A *path* π from a point p to another point q (not necessarily distinct) is a sequence of $\langle p = p_1, p_2, \ldots, p_l = q \rangle$ of points such that every two successive points in the sequence are adjacent (spatially nearby) to each other. The *length* of π is the minimum amount of material needed to traverse to complete a walk along the path. It is calculated as follows:

$$\text{length of } \pi = \sum_{i=1}^{l-1} \tfrac{1}{2}(\mu_{\mathcal{O}}(p_i) + \mu_{\mathcal{O}}(p_{i+1})) \times \| p_i - p_{i+1} \|,$$

where $\mu_{\mathcal{O}}$ is the material density (here, bone volume fraction, short, bvf) function and $\|\cdot\|$ gives the Euclidean distance. There are infinitely many paths between two points. The *fuzzy distance* between two points is the length of the shortest path between them, i.e. the one requiring the minimum amount of material to be traversed from one point to the other. It has been shown in [5] that fuzzy distance satisfies the desired metric property.

The *support* of an object is the set of points with nonzero material density (here, bvf). FDT is an operation that assigns at every point its fuzzy distance from the background – the inverse of the support. The method has been reduced to practice and validated in trabecular bone images of varying resolutions, orientations, and signal-to-noise ratios. Specifically, a dynamic programming-based algorithm for efficient computation of FDT has been conceived and implemented. Let $\Omega_{\mathcal{O}}(p)$ denote the FDT value at p in a fuzzy object (here, bvf mapped image of TB) $\mathcal{O}$ and let $Sk(\Theta(\mathcal{O}))$ denote the skeleton of the support of $\mathcal{O}$. $Sk(\Theta(\mathcal{O}))$ can be computed using currently existing methods. The average thickness of $\mathcal{O}$, denoted by $\tau(\mathcal{O})$ is then computed as

$$\tau(\mathcal{O}) = \frac{\sum_{p \in Sk(\Theta(\mathcal{O}))} 2\Omega_{\mathcal{O}}(p)}{|\, Sk(\Theta(\mathcal{O}))\,|},$$

where, $|\, Sk(\Theta(\mathcal{O}))\,|$ yields the number of points in the skeleton. Although, the target application is trabecular bone images, the method is applicable to images of wide range of elongated structures possessing heterogeneous material distributions and/or fuzzy boundaries generated either by true object properties or by partial volume blurring due to the limited resolution of imaging device.

REFERENCES

[1] S. A. Goldstein, R. Goulet, D. McCubbrey, "Measurement and significance of three-dimensional architecture to the mechanical integrity of trabecular bone," *Calcified Tissue International*, **53,** pp. S127-133, 1993.

[2] J. E. Aaron, R. M. Francis, M. Peacock, N. B. Makins, "Contrasting microanatomy of idiopathic and corticosteroid-induced osteoporosis," *Clinical Orthopedics and Related Research*, **243,** pp. 295-305, 1989.

[3] Rutvitz, D., "Data structures for operations on digital images," in *Pictorial Pattern Recognition*, pp. 105-133, 1968.

[4] G. Levi, U. Montanari, "A gray-weighted skeleton," *Information and Control*, **17,** pp. 62-91, 1970.

[5] P. K. Saha, F. W. Wehrli, B. R. Gomberg, "Fuzzy distance transform - theory, algorithms, and applications," *Computer Vision and Image Understanding*, revised.